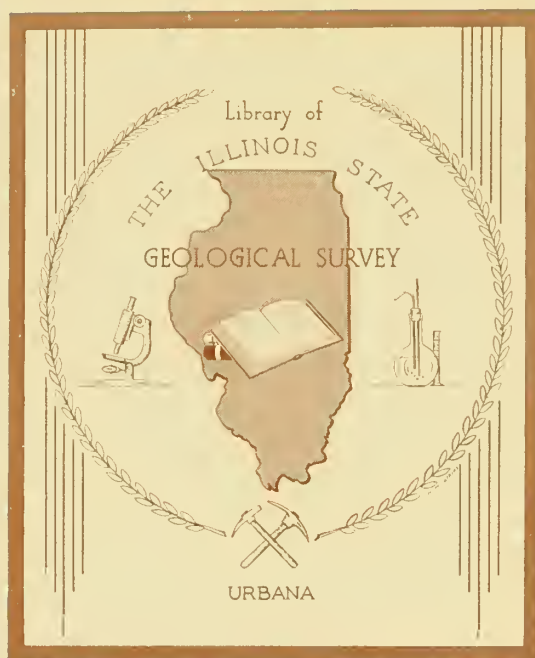






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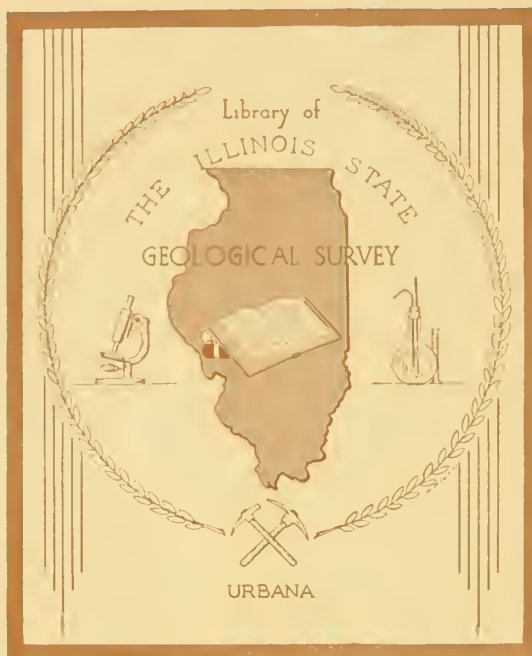
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EFFECTS OF A SOAP, A DETERGENT,
AND A WATER SOFTENER ON THE
PLASTICITY OF EARTH MATERIALS

W. ARTHUR WHITE
SHIRLEY M. BREMSER

ILLINOIS STATE GEOLOGICAL SURVEY

JOHN C. FRYE *Chief • Urbana*



EFFECTS OF A SOAP, A DETERGENT, AND A WATER SOFTENER ON THE PLASTICITY OF EARTH MATERIALS

W. Arthur White and Shirley M. Bremser

Several clay minerals tested in the laboratory showed changes in plasticity after the addition of various amounts of soap, detergent, and water softener.

Earth materials containing clay have sufficient stability in their natural, undisturbed state to provide satisfactory support for many man-made structures. However, the plasticity of such materials may be changed if they are permeated by solutions containing soaps, detergents, water softeners, and other substances that occur in the effluents from septic tanks, oxidation ponds, refuse dumps, and other waste-disposal facilities. Changes include reduction of the plasticity range and liquid limit, with resulting increase in the liquidity index and "sensitivity" of the earth material.

After many years of saturation by waste-disposal effluents, the earth material may be so sensitive that man-made or tectonic disturbances can, under certain conditions, cause the settling of buildings or start disastrous landslides.

When a subdivision with septic tanks or a factory with a pond for waste disposal is planned, the possible effects of wastes on the stability of the underlying earth should be considered.

INTRODUCTION

Almost inevitably, modern man contaminates some parts of the land he occupies. Some of the contaminants are chemical substances that may actually change the physical condition of the earth materials that must support buildings, and the use of some land areas may be seriously affected.

It is possible, for example, that a slope might have sufficient original stability to serve as a residential site. After homes are built and occupied, however, septic tank effluents containing soap, detergents, water softeners, and other organic and inorganic compounds permeate the earth

of the slope. Over a period of years, the clay material undergoes chemical changes and becomes more and more sensitive to disturbances because the chemical repulsive forces between the clay crystals have been increased, making the bonds between the clay particles weaker. Under proper topographic and weather conditions, the sensitive clay may react to vibrations induced either by natural agents, such as earth tremors or quakes, or by those caused by man, such as the passing of heavy trucks. It may creep slowly or a landslide may develop with resultant property damage, or even personal injury or loss of life.

Merriam (1960, p. 150) suggested that the Portuguese Bend landslide near Los Angeles was attributable to the water from the cesspools of 150 houses. Soderblom (1966, p. 2) indicated that rainwater dissolving chemicals from a waste dump and filtering through a normal clay changed it into a quick clay in less than 20 years. A quick clay is solid until disturbed; it then becomes fluid and flows as a viscous liquid.

In order to evaluate the effects of such changes on the physical environment, and hence the influence upon the stability of slopes and of the earth materials beneath and around man-made structures, the Illinois State Geological Survey has undertaken a study that attempts to show the changes induced in clay minerals by soap, detergent, and water softener, and in the stability characteristics of unconsolidated rock materials that constitute most of the surficial deposits of Illinois.

OCCURRENCE AND CHARACTER OF CLAY MINERALS

The unconsolidated earth materials of Illinois occur in layers on an irregular bedrock surface, which was shaped by erosion into hills and valleys composed of older (pre-Pleistocene) bedrock. However, each layer (fig. 1) does not necessarily have the same geographic distribution as the layer above or the one below. The surface of several of these layers was eroded into hills and valleys before the layer above was deposited. Each layer may vary in thickness from one geographic location to another, and any layer may differ in thickness from those above and below. Loess, till, and lake clay layers all contain clay minerals.

Engineering geologists and geological and civil engineers have been aware of the problems of building dams, roads, tunnels, and foundations of large buildings in, on, through, and with earth materials containing clay minerals. They know that problems such as instability of slopes, shrinking and swelling under foundations, and plastic flow of clay materials from beneath structures depend on the kinds and abundance of clay minerals present in the earth. The common clay minerals are illite, kaolinite, chlorite, montmorillonite, and mixed-layer clay minerals, all of which occur in Illinois. The clay mineralogy of one layer of earth material may be the same throughout, but in another layer it may vary from one geographic

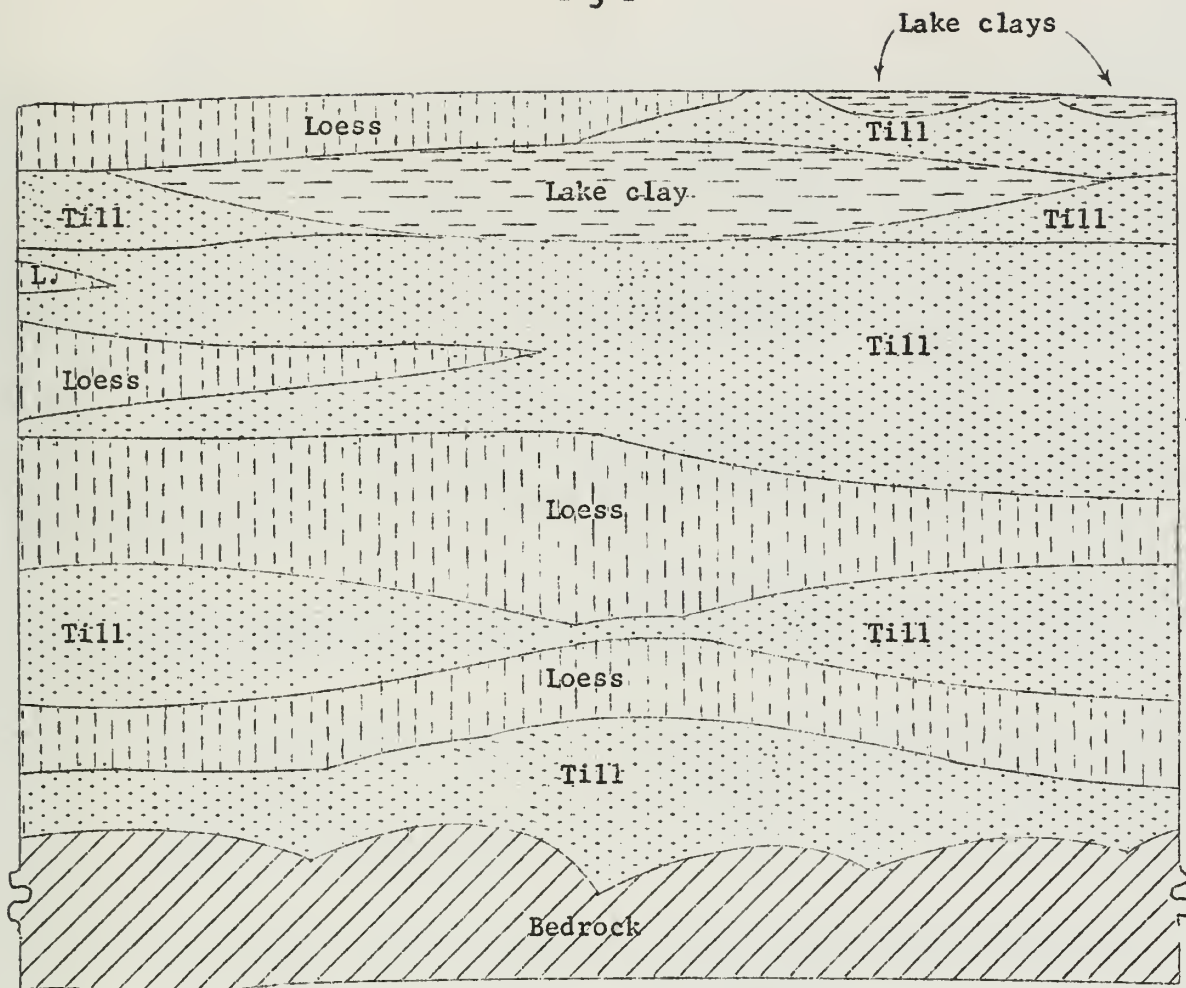
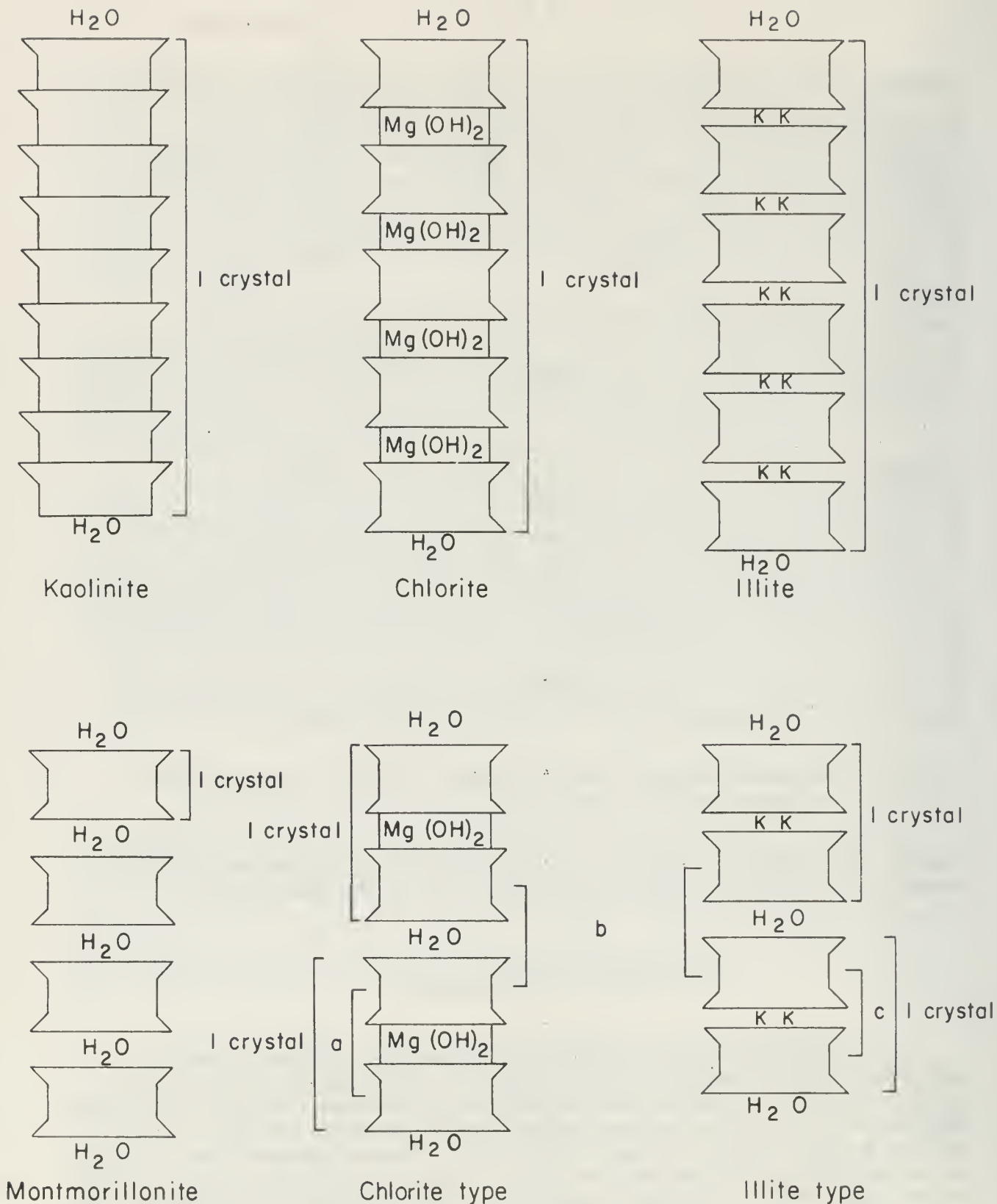


Fig. 1 - Schematic diagram showing typical layering of unconsolidated earth materials in Illinois.

location to another or from the top of the layer to the bottom. The percentages of clay and nonclay minerals may vary in the same manner.

PROPERTIES OF CLAY MINERALS

Properties such as plasticity, viscosity, shrinkage, swelling, and workability of each clay mineral are controlled by parameters such as crystal structure, particle size distribution, adsorbed exchangeable cations, soluble salts in the water surrounding the clay mineral particles, and the ability to adsorb certain organic molecules. The clay minerals will exchange one cation for another in the same way that the compounds in water softeners soften hard water. Sodium in the softener is exchanged for calcium in the hard water, and calcium is exchanged for sodium in the salt when the softening compound is regenerated. Each clay mineral has a certain arrangement of atoms (fig. 2) that is repeated to form the crystal structure. Each clay mineral will have at least one atom that makes it different from another clay mineral.



MIXED-LATTICE CLAY MINERALS

Fig. 2 - Schematic drawings of the structures of clay minerals showing how the basic cells are bonded together. H_2O = water; $Mg(OH)_2$ = brucite sheet; K = potassium; a = part of crystal that has the properties of chlorite; b = part of crystal that has the properties of montmorillonite; c = part of crystal that has the properties of illite.

If we change any one of these parameters for the clay minerals, the properties of the earth material will change also. The farmer or gardener knows that if his soil is tight and hard when it dries out, he can lime the soil to increase its tilth. The tilth, which is the property of a soil that makes it loose and crumbly, is increased because the calcium of the lime replaces the hydrogen on the clay and changes the properties of the clay minerals. He also knows that if he adds organic matter such as manure, peat, or compost, he will increase the tilth. In both instances, he is changing the properties of the clay minerals in the soil.

Clay, when mixed with water, becomes plastic; that is, it can be "worked" or formed into objects that will retain their shapes, such as a vase a potter forms on his wheel. The plasticity of clay minerals has been studied at the Survey for some time (Grim, 1941, 1942, 1948; White, 1949, 1954, 1958).

In dealing with clays, their plastic properties, and their moisture contents, the following terms should be defined and their mutual relationships shown:

- 1) The liquid limit. This is the highest moisture content, expressed in percentage based on oven-dried clay, at which a clay can be shaped into a small object and subsequently retain that shape. At moisture contents higher than the liquid limit, the clay will flow under its own weight.
- 2) The plastic limit. This is the lowest percentage of moisture a clay can contain and still be shaped. With less moisture the clay will break or crumble during molding.
- 3) The plasticity range — sometimes called the plasticity index. This is merely the difference between the liquid limit and the plastic limit. The higher the moisture content within the plasticity range, the lower the force required to shape the clay into a desired form.

(The three above indices are known as the Atterberg limits.)

- 4) Activity value. This is a value used to compare the plasticity ranges of clay minerals in earth materials without actually removing the nonclay substances from the earth materials. It is obtained by dividing the plasticity range of the natural earth material by the percentage of material it contains that is smaller than 2 microns. Multiplying the activity value by 100 gives the plasticity range of the clay minerals in the earth material.
- 5) Natural water content. This is the percentage of water in a saturated clay as it occurs naturally. Skempton (1953, p. 41) stressed its significance in relation to the Atterberg limits, and this relation is expressed by a liquidity index.

$$\begin{aligned} 6) \text{ Liquidity index} &= \frac{\text{natural water content} - \text{plastic limit}}{\text{liquid limit} - \text{plastic limit}} \\ &= \frac{\text{natural water content} - \text{plastic limit}}{\text{plasticity range}} \end{aligned}$$

When the natural water content and the liquid limit are the same, the liquidity index is 1.

Now if the introduction of a chemical, such as a detergent, into an earth material reduces the liquid limit, and hence also reduces the plasticity range, the liquidity index will become greater than 1. If, for example, a material had a natural water content of 60 percent, a liquid limit of 60 percent, and a plastic limit of 20 percent, the liquidity index would be

$$\frac{60 - 20}{60 - 20} = 1;$$

but if the liquid limit of this material were reduced to 40, the liquidity index would be

$$\frac{60 - 20}{40 - 20} = \frac{40}{20} = 2.$$

The clay would now be a quick clay that would flow under its own weight if disturbed; it would be very sensitive.

In most tills, the natural water content is below the liquid limit. If a till has a natural water content of 35 percent, a liquid limit of 45 percent, and a plastic limit of 25 percent, the liquidity index would be

$$\frac{35 - 25}{45 - 25} = \frac{10}{20} = 0.5.$$

If the liquid limit is reduced from 45 to 40, the liquidity index will increase from 0.5 to 0.67:

$$\frac{35 - 25}{40 - 25} = \frac{10}{15} = 0.67.$$

The lowering of the liquid limit and the increasing of the liquidity index suggest that the earth material, even when undisturbed, may be potentially more sensitive than the untreated material.

The earth material in both examples (first, the change of liquidity index from 1 to 2, and second, the change from 0.5 to 0.67) will be as strong after the introduction of the chemical as before, as long as it is not disturbed. However, if the clays are disturbed, the first will flow as a liquid, while the second will move a little more rapidly than it would have before the introduction of the chemical, provided a suitable force is being exerted upon it; the movement would probably be plastic in nature.

The plasticity range for montmorillonite is greater than that for illite and, in turn, the plasticity range for illite is greater than that for kaolinite. Chlorite has plastic properties similar to those of illite, and the mixed-layer clay minerals have plastic properties between those of illite and montmorillonite.

As the average particle size of each clay mineral decreases, its liquid limit and plasticity range increase, if all other variables are held constant. The exchangeable cation on the surface of the clay minerals also influences the plastic properties and water sorption properties when all other variables are held constant.

Rosenqvist (1955, p. 72) found that the plastic limit was affected little by the salinity of the water in the clay, but that the liquid limit and plasticity range could be changed considerably by changing that salinity. The exchangeable cations have little effect on the plastic limits of any clay mineral except montmorillonite, but the change for the liquid limit and plasticity range varies for each. There is little change for kaolinite but a large one for montmorillonite.

CLAY MINERALS INVESTIGATED

The kaolinite used for this investigation was from the Spoon Formation at the base of the Pennsylvanian sequence of rocks. The sample was taken at NW $\frac{1}{4}$ SW $\frac{1}{4}$ NW $\frac{1}{4}$ sec. 10, T. 4 S., R. 5 W., Pike County, Illinois. This clay was about 80 percent kaolinite, 15 percent quartz, 2 percent titanium oxide, and 3 percent illite. About 40 percent of the clay was broken down to a size of less than 2 microns, and the remaining 60 percent was kaolinite and quartz larger than 2 microns.

The Grundy County clay tested was from the Spoon Formation of Pennsylvanian age and was taken from the Illinois Clay Products pit, sec. 11, T. 33 N., R. 8 E., Grundy County, Illinois. The clay was composed of mixed-layer clay minerals, illite, and about 10 percent kaolinite. Fifty percent of the sample was in the less-than-2-micron fraction.

The Fithian illite was an underclay below a coal in the Bond Formation of Pennsylvanian age and was located in W $\frac{1}{2}$ sec. 31, T. 19 N., R. 13 E., Vermilion County, Illinois. The clay minerals were illite and mixed-layer clay minerals, and the sample contained more illite and less mixed-layer clay minerals than the Grundy County illite. Thirty percent of the sample was less than 2 microns in size.

The montmorillonite from Wyoming was Cretaceous in age and was obtained from the American Colloid Company, Skokie, Illinois. About 75 percent of the particles were less than 2 microns in size. Its cation exchange capacity is 93 me/100 gm. Sodium was the exchangeable cation.

The Mississippi montmorillonite tested was Cretaceous in age and was obtained from International Minerals and Chemical Company, Skokie,

Illinois. About 75 percent of the particles of this clay were less than 2 microns. Its cation exchange capacity was 93 me/100 gm. Calcium was the exchangeable cation.

PROCEDURE

The samples of kaolinitic and illitic clays were divided into two parts, one to be tested without further processing and the other to be washed to remove its soluble salts so that it could be fractionated. Fractionation was achieved by mixing the clay with distilled water and allowing the particles to settle. Some of the water was then drawn off to a given depth after a given time and the clay in suspension was recovered for the less-than-2-micron fraction.

The less-than-2-micron fraction of the illitic and kaolinitic clays and the whole sample of montmorillonite were then treated with various amounts of soap, detergent, and water softener. Atterberg limits were determined for both the whole, untreated sample and the treated fraction of each clay mineral.

RESULTS OF INVESTIGATIONS

The plasticity and activity data for the clays tested are shown in tables 1 through 6. The plasticity range for the whole sample of each clay mineral was lower than that for the less-than-2-micron fraction (tables 1, 2, and 3). However, when the activity value for the clay minerals within the whole sample and the value of the separated less-than-2-micron sample are compared (table 6), the clay minerals remaining in the whole sample have a greater plasticity range than those in the less-than-2-micron sample. This could be due to the presence of soluble salts in the whole sample.

The data in table 1 show that, compared with values for the untreated less-than-2-micron fraction, soap and 2 percent or less of water softener have little effect on the plastic properties of kaolinite, but 5 percent or more of water softener increases the plasticity range. The detergent reduced the plasticity range at all concentrations.

Table 2 shows that, compared with the untreated less-than-2-micron fraction, 0.5 and 1.0 percent detergent and 0.5 percent water softener reduce the plasticity range of the illitic clay from Grundy County, whereas, other concentrations have little effect. Ten grams of soap per 250 grams of clay increased the plasticity range about 28 percent.

The data in table 3 show that all percentages of water softener and 0.5 through 5 percent detergent reduced the plasticity range for the illite from Fithian, Illinois, in comparison with the value for the untreated less-than-2-micron fraction. Ten percent detergent had little effect on the

TABLE 1 - ATTERBERG LIMITS FOR KAOLINITE

Samples and additives	Liquid limit	Plastic limit (in percent of water)	Plasticity range
Untreated samples			
Whole	30	19	11
< 2 μ	50	30	20
Treated samples (< 2 μ)			
Detergent - percent			
0.5	47	29	18
1.0	41	28	13
2.0	42	28	14
5.0	46	32	14
10.0	44	30	14
Water Softener - percent			
0.5	46	28	18
1.0	47	27	20
2.0	44	26	18
5.0	50	26	24
10.0	58	26	32
Soap - gm/250 gm clay			
0.5	47	27	20
1.0	49	28	21
2.5	46	28	18
5.0	46	29	17
10.0	53	30	23

plastic properties, and the soap had appreciable effect only for the 10-gram sample, which increased the plasticity range.

In table 4 the data for the montmorillonite from Wyoming, which contained sodium as an exchangeable cation, showed that all percentages of detergent and water softener and 0.5, 1.0, and 2.5 grams of soap per 100 grams of clay decrease the plasticity range, whereas 5.0 and 10.0 grams of soap per 100 grams of clay increase it, compared with values for the untreated sample.

The montmorillonite from Mississippi, which contained calcium as an exchangeable cation, showed (table 5) increases in plasticity range over the untreated sample for all concentrations of detergent, soap, and water softener. The increase is probably due to the exchange of calcium on the clay for sodium on the soap, detergent, and water softener, producing a sodium montmorillonite.

TABLE 2 - ATTERBERG LIMITS FOR ILLITE FROM GRUNDY COUNTY

Samples and additives	Liquid limit	Plastic limit (in percent of water)	Plasticity range
Untreated samples			
Whole	68	24	44
<2 μ	101	36	65
Treated samples (<2 μ)			
Detergent - percent			
0.5	94	36	58
1.0	95	37	58
2.0	100	37	63
5.0	104	37	67
10.0	104	37	67
Water Softener - percent			
0.5	90	35	55
1.0	101	36	65
2.0	104	35	69
10.0	99	38	61
Soap - gm/250 gm clay			
0.5	102	36	66
1.0	102	37	65
2.5	106	39	67
5.0	108	39	69
10.0	123	40	83

DISCUSSION OF POSSIBLE CONDITIONS

Glacial tills containing illite, chlorite, kaolinite, and mixed-layer clay minerals contain fissures along which solutions can move, and the clay minerals along the surfaces of the fissures can react with chemicals in the solutions. The clay is then potentially more sensitive along these surfaces. These tills would have plastic properties similar to clay reported in tables 1, 2, and 3 and would probably behave as suggested on page 6.

Materials like loess and lake silts may allow water to filter through to an impermeable layer and may even allow seepage along hillsides and bluffs. The slope could then become quite unstable.

Most of the loess deposits (Frye, Glass, Willman, 1962) of the state, till deposits in western Illinois (Willman, Glass, Frye, 1963), and Illinoian glacial lake and Cretaceous deposits in western Illinois (Frye, Willman, Glass, 1964) may contain appreciable quantities of montmorillonite

TABLE 3 - ATTERBERG LIMITS FOR ILLITE FROM FITHIAN, ILLINOIS

Samples and additives	Liquid limit	Plastic limit (in percent of water)	Plasticity range
Untreated samples			
Whole	50	26	24
<2 μ	76	36	40
Treated samples (<2 μ)			
Detergent - percent			
0.5	64	34	30
1.0	62	33	29
2.0	66	36	30
5.0	68	35	33
10.0	76	35	41
Water Softener - percent			
0.5	57	33	24
1.0	62	35	27
2.0	61	34	27
5.0	58	33	25
10.0	57	32	25
Soap - gm/250 gm clay			
0.5	70	34	36
1.0	77	37	40
2.5	76	35	41
5.0	77	39	38
10.0	87	38	49

that has calcium as an exchangeable cation. White (1958, p. 23-26) showed that montmorillonite containing exchangeable calcium will adsorb water and swell, and that the same montmorillonite treated so that it contains sodium as the exchangeable cation will adsorb several times more water. The liquid limits and plasticity ranges for the montmorillonite (table 5) in which the exchangeable cation is calcium increased as the concentrations of soap, detergent, and water softener were increased. This was probably brought about by the exchange of the sodium from the three additives mentioned above for the exchangeable calcium on the clay surface.

If septic tank fields are placed in loess anywhere in Illinois and in till, glacial lake, and Cretaceous deposits in western Illinois, the exchange of sodium for calcium in these deposits could increase the differential shrinkage during drouth and swelling during wet periods. After a few years, damage to foundations of buildings, sidewalks, and streets could result.

TABLE 4 - ATTERBERG LIMITS FOR MONTMORILLONITE FROM WYOMING

Samples and additives	Liquid limit	Plastic limit (in percent of water)	Plasticity range
Untreated sample			
Whole	692	48	644
Treated sample			
Detergent - percent			
0.5	609	34	575
1.0	596	35	561
2.0	594	38	556
5.0	577	38	539
10.0	566	46	520
Water Softener - percent			
0.5	573	36	537
1.0	560	37	523
2.0	529	39	490
5.0	515	39	476
10.0	461	40	421
Soap - gm/100 gm clay			
0.5	626	35	591
1.0	642	38	604
2.5	662	40	622
5.0	732	41	691
10.0	693	41	652

Further studies are being made on the effect of soaps, detergents, and water softeners on the properties of earth materials.

SUMMARY

Earth deposits saturated with effluent from septic tank fields, oxidation ponds, refuse dumps, and other waste disposal facilities may become sensitive and potentially unstable after a number of years. When disturbed by man-made or natural vibrations, the saturated deposits may move as creep or as landslides. In areas where calcium-saturated montmorillonite is present the effluents may increase the swelling by exchanging their sodium for the calcium on the clay.

TABLE 5 - ATTERBERG LIMITS FOR MONTMORILLONITE FROM MISSISSIPPI

Samples and additives	Liquid limit	Plastic limit (in percent of water)	Plasticity range
Untreated			
Whole	153	45	108
Treated			
Detergent - percent			
0.5	187	47	140
1.0	205	48	157
2.0	235	52	183
5.0	272	55	217
10.0	331	60	271
Water Softener - percent			
0.5	191	48	143
1.0	206	53	153
2.0	257	53	204
5.0	297	46	251
10.0	307	51	256
Soap - gm/100 gm clay			
0.5	184	45	139
1.0	184	48	136
2.5	224	48	176
5.0	244	50	194
10.0	246	52	194

TABLE 6 - ACTIVITY VALUES FOR THE CLAY MINERALS

Samples and additives	Kaolinite	Grundy County illite	Fithian illite	Wyoming montmorillonite	Mississippi montmorillonite
Untreated samples					
Whole	.28	.84	.56	8.54	1.42
<2 μ	.20	.65	.40		
Treated samples (<2 μ)					
Detergent - percent					
0.5	.17	.58	.30	7.62	1.83
1.0	.13	.58	.29	7.43	2.05
2.0	.14	.63	.30	7.36	2.40
5.0	.14	.67	.33	7.14	2.84
10.0	.14	.67	.41	6.89	3.55
Water Softener - percent					
0.5	.18	.55	.24	7.11	1.87
1.0	.20	.65	.27	6.93	2.00
2.0	.17	.69	.27	6.49	2.67
5.0	.24	.54	.25	6.31	3.29
10.0	.32	.66	.25	5.58	3.35
Soap - gm					
	per 250 gm of clay			per 100 gm of clay	
0.5	.20	.66	.36	7.33	1.82
1.0	.21	.65	.40	8.00	1.78
2.5	.18	.67	.41	8.24	2.30
5.0	.17	.69	.38	9.15	2.54
10.0	.23	.83	.49	8.64	2.54

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